2013 EUVL Workshop

A New Design Method for Extreme Ultraviolet Lithographic Objective

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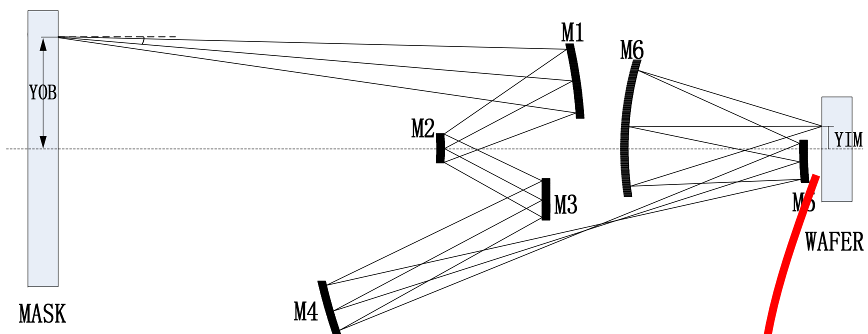
OUTLINE

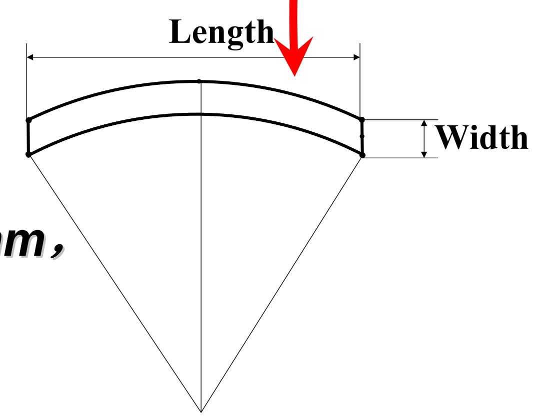
- Introduction
- **Grouping Design Solution**
- **Description of Design Method**
- Gradual Optimization
- Performance of the Objective
- Conclusions

Introduction

1. Constrains in objective design for EUVL



Arc shaped field：



Field width: 1~2mm，
Chord length: 22-26mm，

Design requirements:

- ***Non-obstruction***
- ***High Resolution***
- ***Very low distortion***
- ***Telecentricity on image side***
- ***Total Tack***
- ***Accessible aperture stop***
- ***Working distance***
- ***Low aspheric departure***
- ***Small angle of incidence***
- ***Even mirrors.***

Others: ……………..

2. Trend of NA of reflective objective

ADT
NEX 3100

NEX 3300

k_1					
HP	45nm	32nm	22nm	16nm	11nm
NA0.25	0.83	0.59	0.41	0.30	
NA0.30		0.71	0.49	0.36	
NA0.33		0.78	0.54	0.39	
NA0.35		0.83	0.57	0.41	0.29
NA0.40			0.65	0.47	0.33
NA0.45			0.73	0.53	0.37
NA0.50					
NA0.60					
NA0.70					

$$RES = \frac{k_1 \cdot \lambda}{NA}$$

Need new design strategy!

Initial configuration of objective is most important !

3. Design methods of EUVL objective

Paraxial model

M.F. Bal, 2003

Ray matrix $$\begin{pmatrix} y_{N+1} \\ u_{N+1} \end{pmatrix} = \mathrm{M} \cdot \begin{pmatrix} h \\ u_0 \end{pmatrix} + O(3)$$

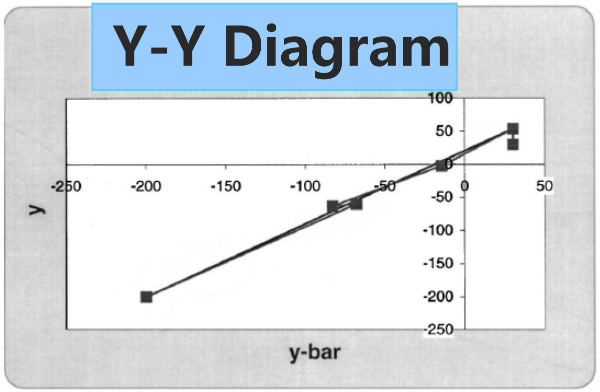
Transfer matrix $$\mathrm{T}_i = \begin{bmatrix} 1 & d_i \\ 0 & 1 \end{bmatrix}$$

Reflection matrix $$\mathrm{R}_i = \begin{bmatrix} 1 & 0 \\ c_i \frac{n_{i-1} - n_i}{n_i} & \frac{n_{i-1}}{n_i} \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 0 \\ -2c_i & -1 \end{bmatrix}$$

exhaustive search of all Independent variables.

Scott A. Lerner, 2000

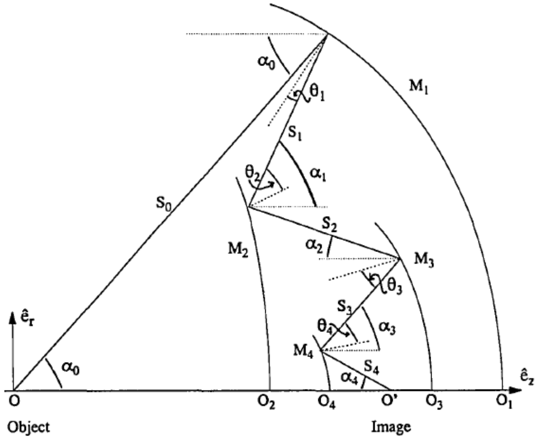
Y-Y Diagram



4-mirrors objective

C. Wang,1992

Differential equation



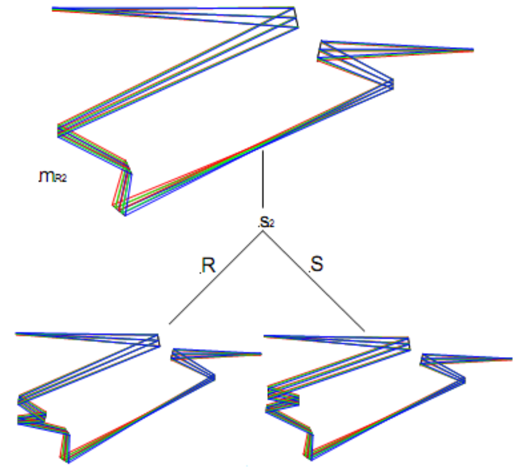
Real Ray Tracing

Assuming mirrors figures(M1, M4) as known parameters

4-mirrors objective

Saddle Point

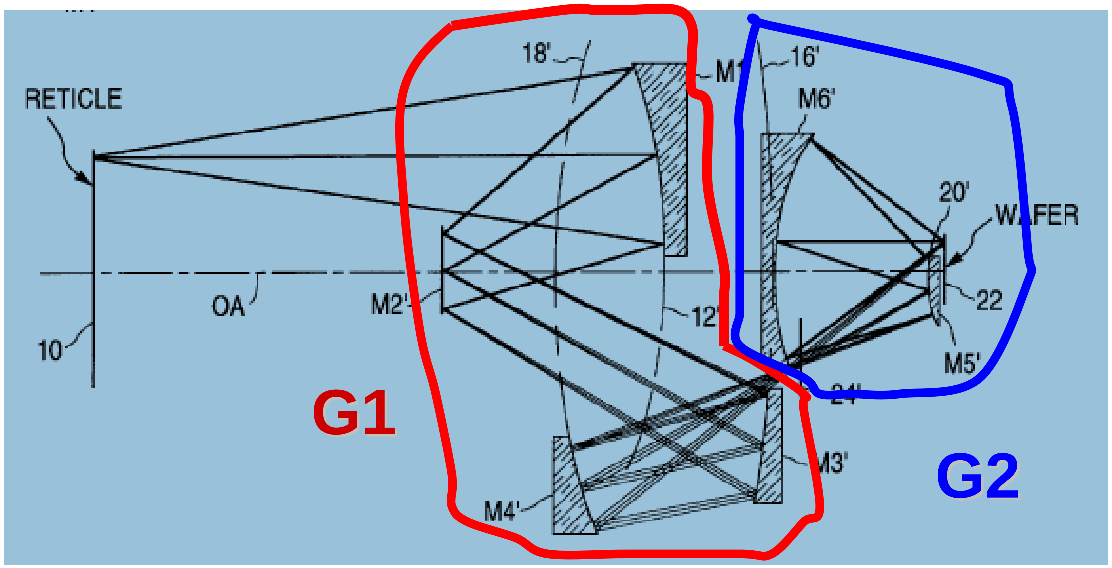
O. E. Marines, 2006



Ideas for multi-elements

3. Design methods of EUVL objective

Russell Hudyma, US Patent: 6033028, 2000.



IDEA about Grouping Design

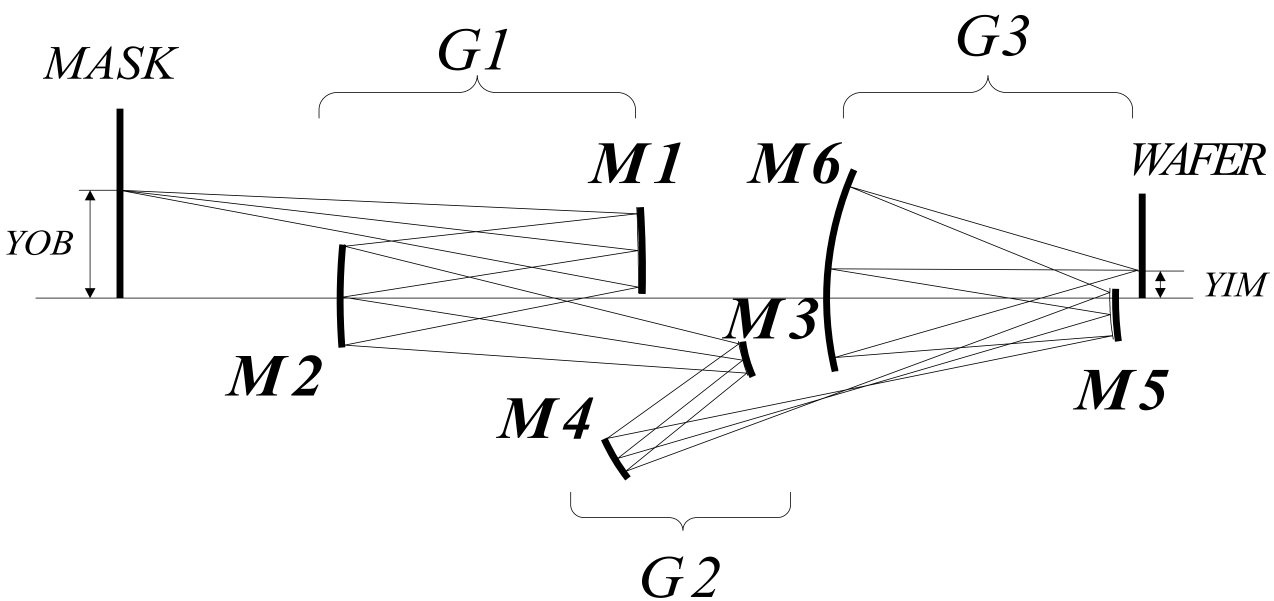
G1: M1, M2, M3, M4
G2: M5, M6

Detailed design method was not mentioned.

Introduction

Fei Liu and Yanqiu Li* , ODF 2012, Optical Review, 2013

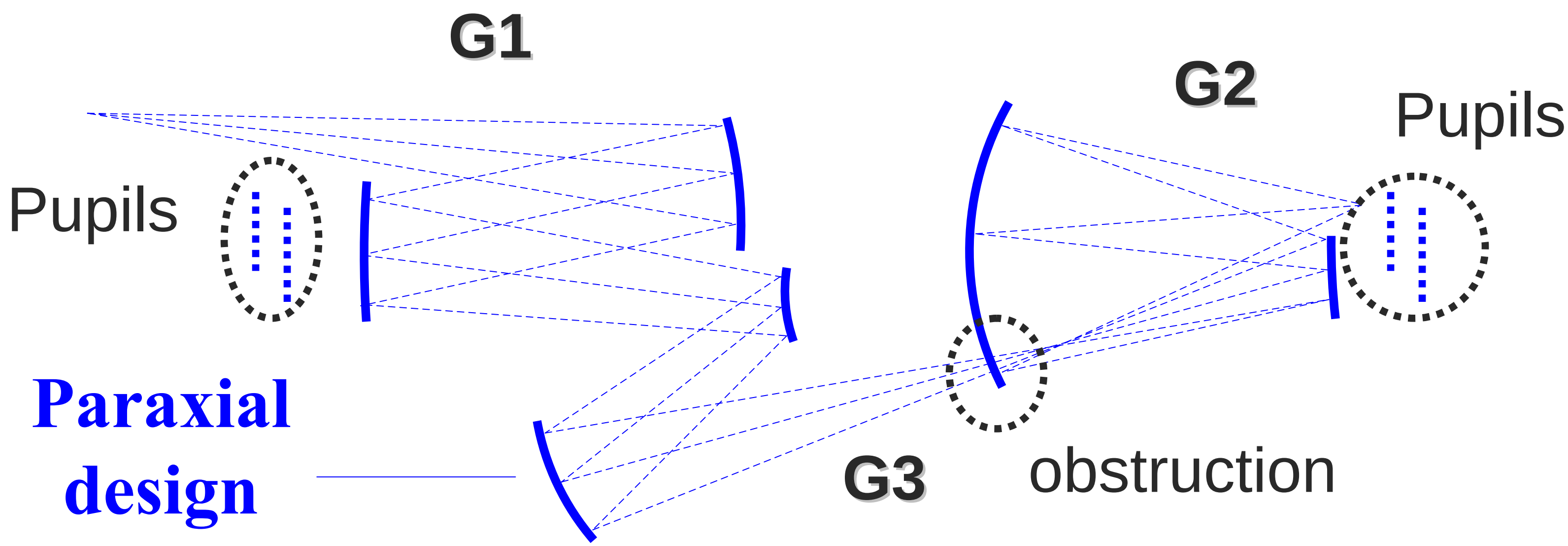
We presented grouping design method with paraxial calculation.



G1 : M1, M2
G2: M3, M4
G3: M5, M6

G1, G2 and G3 is design individually, then they are connected to be an initial configuration of Objective

Problems:



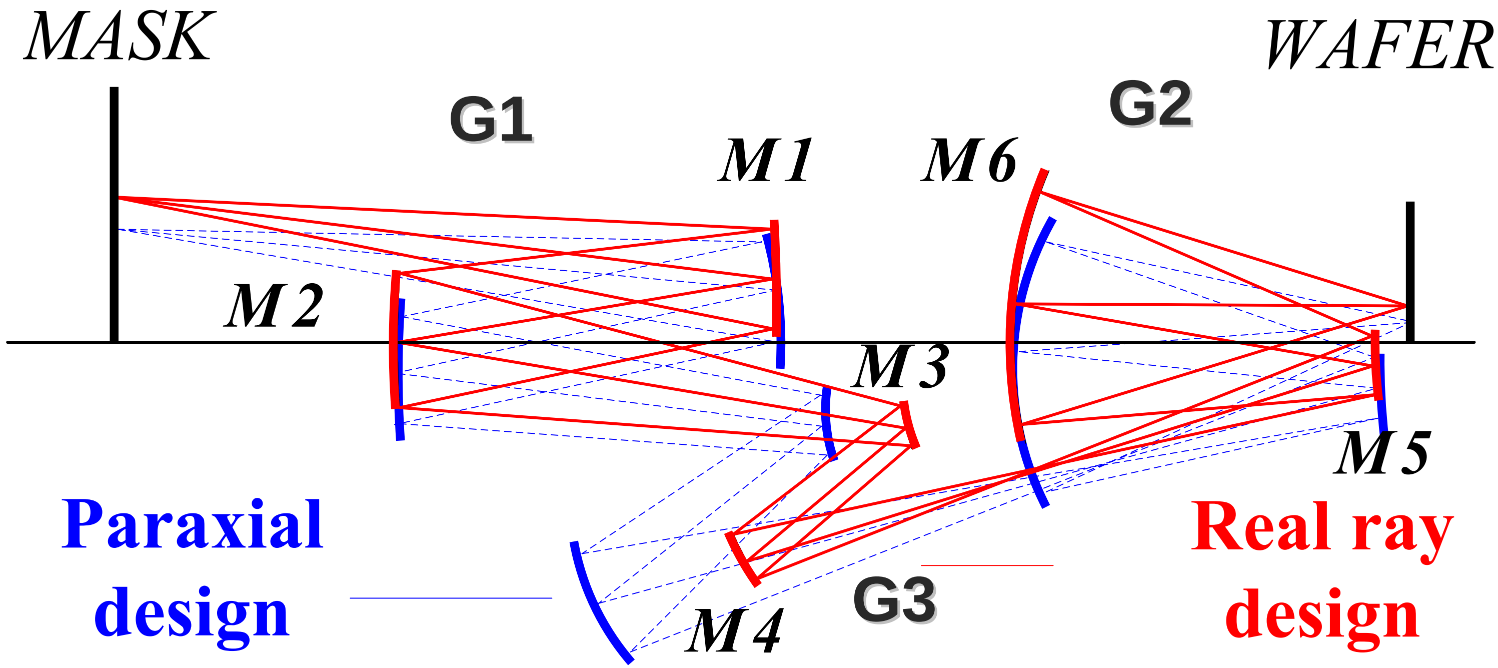
Problems:,

➢*Connection of each group may cause that pupils are mismatched, and there may be obstruction, because of paraxial approximation*

➢*We have to make an iterative calculation get an initial objective .*

4. What is New in this presentation

- ➢**Grouping design method with off axis real rays tracing**



Pupils are matched exactly, there is no obstruction!

Real rays are connected perfectly without iterative calculation.

Beam angles can be controlled in each design process.

Our Grouping Design Solution

Grouping strategy

- G1: Object side group
- G2: Middle group
- G3: Image side group

Parameter calculation constraints

- Non-obstruction
- Pupil stop condition
- Conjugation condition
- Design requirements

Group parameter calculation

Defined the parameters

- Parameters of G1
- Parameters of G3
- Parameters of G2

Connecting Groups

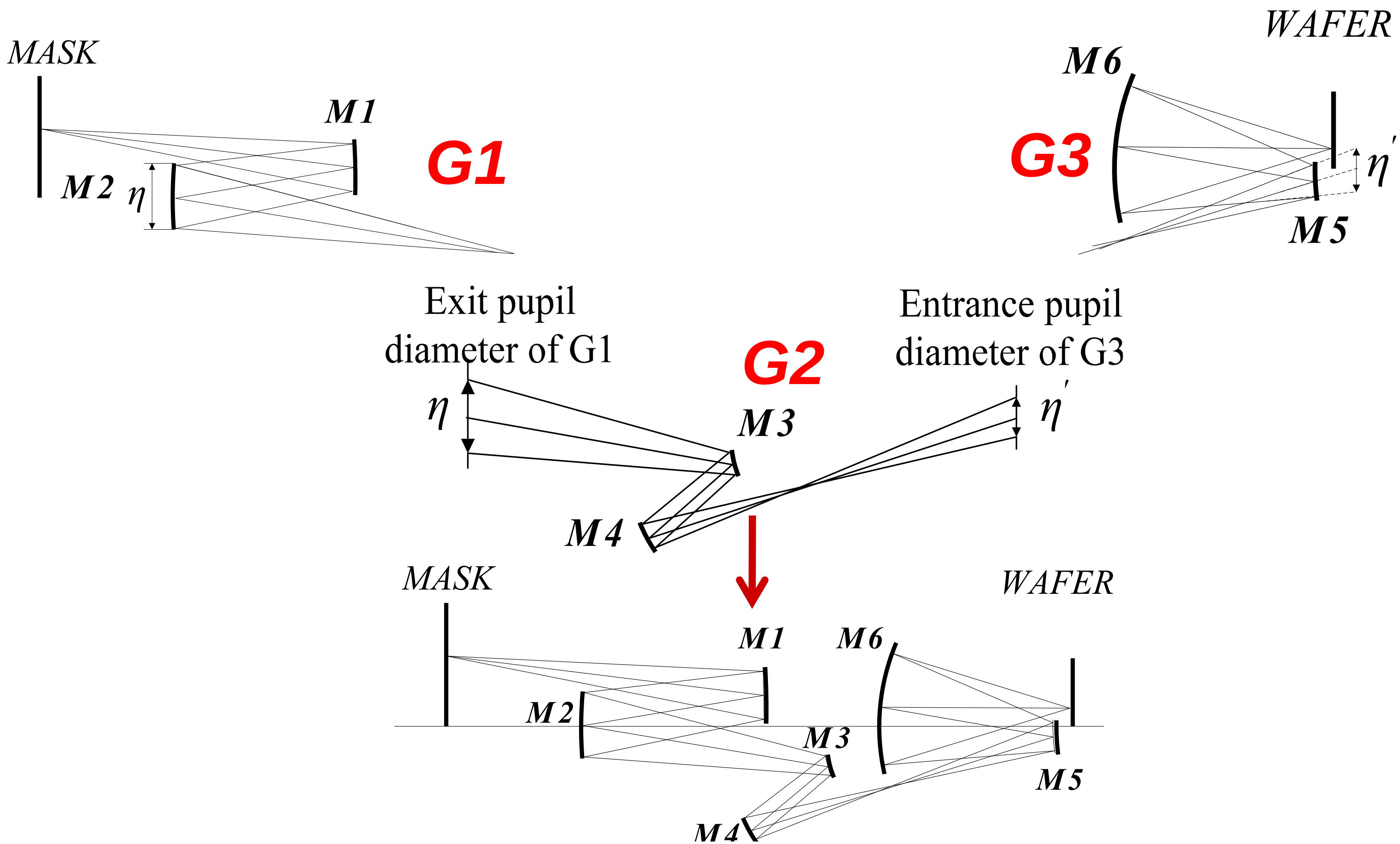
Initial spherical structure

Gradual optimization

Final aspheric system

Before we calculate the initial design parameters, we

1. Grouping strategy



Spherical initial configuration

2. Parameter calculation constraints

Pupil stop constraint: ***If stop is set on a mirror M2,***

surface parameter (e.g. radius of mirrors) is a function of the pupil or stop position (or diameter).

$$y_1 = f_a\left(x_1, x_2 \ldots x_n, CA_1, CA_2 \ldots CA_m\right)$$

$CA_1, CA_2 \cdots CA_m$ **are the chief ray tracing data .**

$x_1, x_2 \cdots x_n$ **are the given or defined parameters**

y_1 **is the unknown surface parameter**

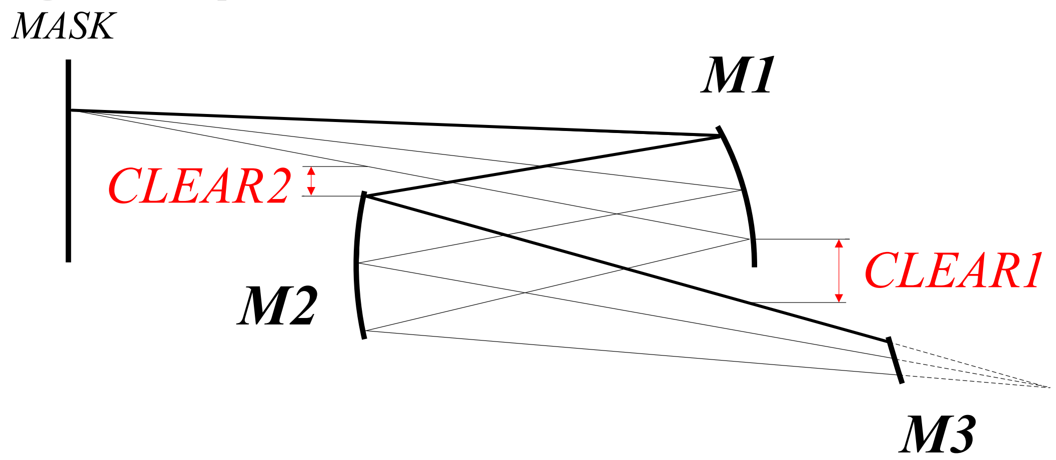
For example:
M1 radius,

$$r_1 = h_{z1} \Big/ \sin\left\{\frac{CA}{2} - \frac{\arctan\left[h_{z1} / (-d_1 + z_{z1})\right]}{2}\right\}$$

Angle constraint: **arcsin $NA_{obj} < CA = CA_{mask} < 6^0$**

Non-obstruction constraint:

Surface parameter can be expressed as a function of clearance and the given parameters.



Clearance: ***the space between the used mirror segment edge and the beam near this mirror :***

$$y_1 = f\left(x_1, x_2 \cdots x_n, CLEAR1\right)$$

$x_1, x_2 \cdots x_n$ ***are the given or defined parameters.***

y_1 ***is the unknown surface parameter.***

Conjugation condition: **surface parameter should match the adjacent groups' characteristic (e.g. whole system meet the pizval sum condition).**

Obj-im conjugation:

$$\frac{1}{l_1}+\frac{1}{l_1'}=\frac{2}{r_1},l_2-l_1'=-d_1,\frac{1}{l_2}+\frac{1}{l_2'}=\frac{2}{r_2}\cdots\frac{1}{l_n}+\frac{1}{l_n'}=\frac{2}{r_n}$$

Pupil conjugation:

$$\frac{1}{(l_1-enp)}+\frac{1}{l_{p1}'}=\frac{2}{r_1},l_{p2}-l_{p1}'=-d_1,\frac{1}{l_{p2}}+\frac{1}{l_{p2}'}=\frac{2}{r_2}\cdots\frac{1}{l_{pn}}+\frac{1}{l_{pn}'+exp}=\frac{2}{r_n}$$

Magnification:

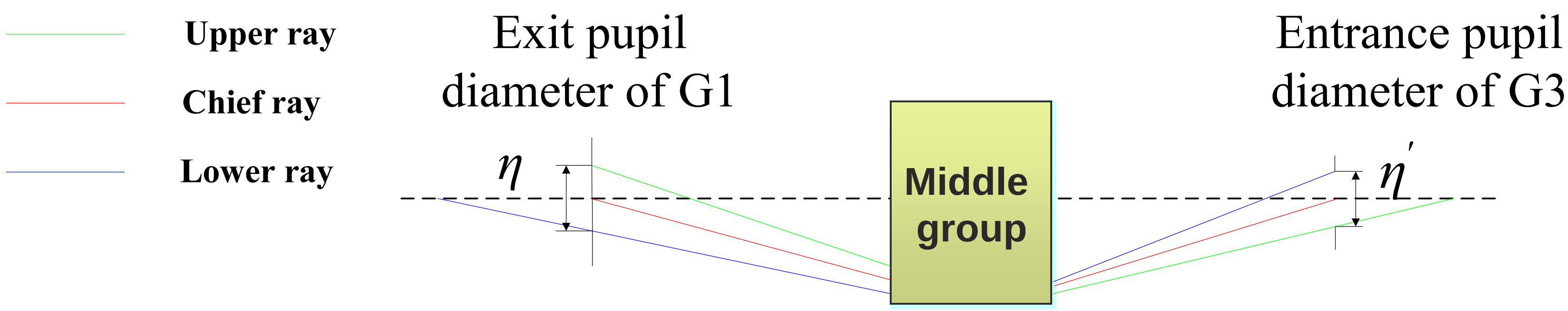
$$\frac{l_n'}{l_n}\cdot\frac{l_{n-1}'}{l_{n-1}}\cdots\frac{l_1'}{l_1}=\beta$$

3. Parameter calculation constraints

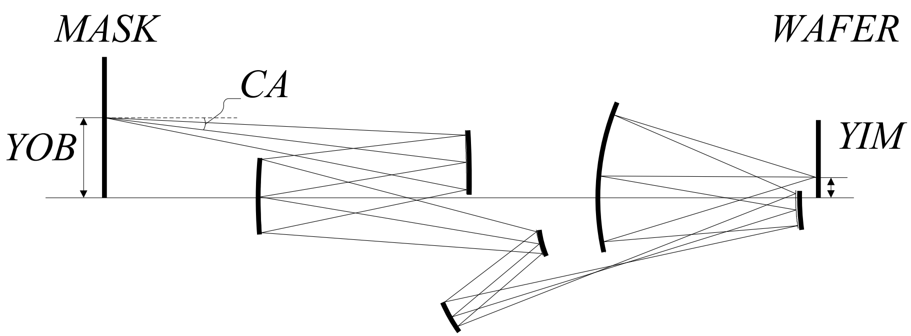
Petzval sum condition

$$\sum_{i=1}^{N}(-1)^i c_i = 0$$

Conjugation condition: Middle group should connect the exit pupil of object-side group with the entrance pupil of image-side group .



4. Parameters calculations



Defined parameters :

M Magnification

CA Chief ray angle on mask

NA Numerical aperture on image side

NAO **Numerical aperture on object side:**

$$NAO = NA \times |M|$$

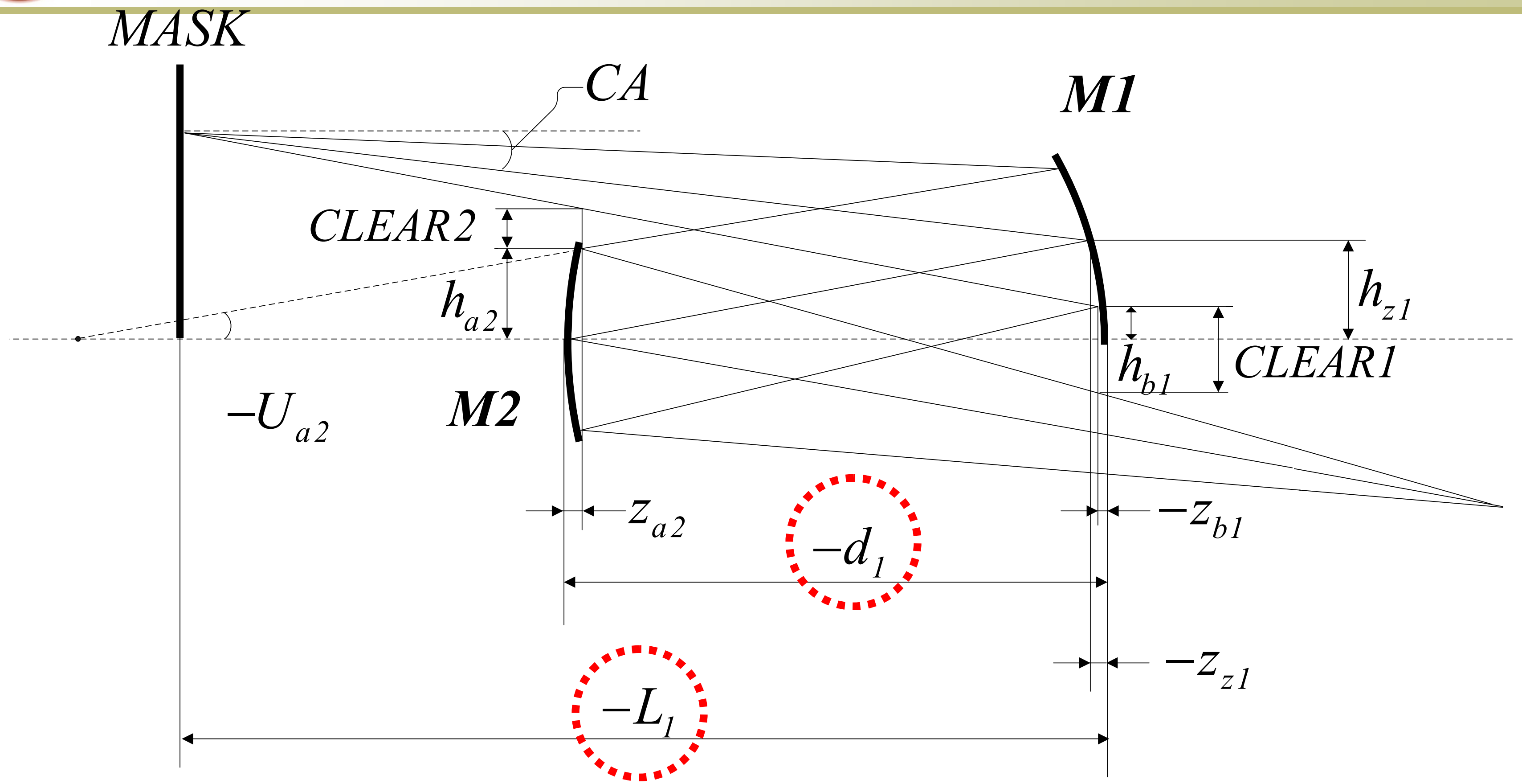
YOB **Object height:**

$$YOB = YIM \,/\, |M|$$

YIM Image height

They are obtained from design requirements.

G1: Object side group



At first: we choose the adequate L_1 ***and*** d_1 ***due to the total track and incidence angles constraints***

G1:Object side group

r_1 : **radius of M1,** r_2 : **radius of M2**

The mirror radius can be calculated with the defined parameters and constraints:

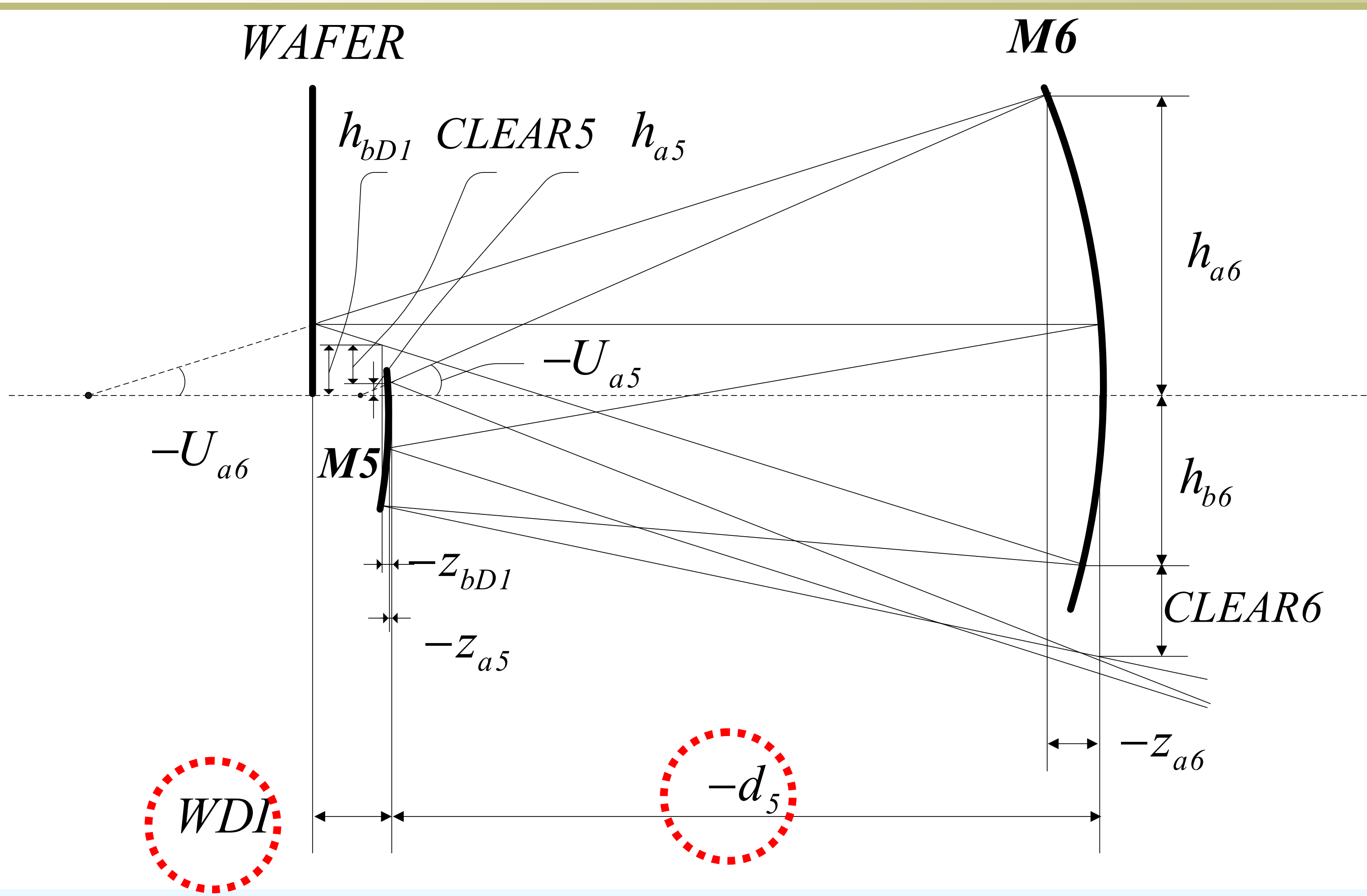
- **Pupil stop constraint:**

$$r_1 = h_{z1} \Big/ sin\left\{\frac{CA}{2} - \frac{arctan\left[h_{z1} / (-d_1 + z_{z1})\right]}{2}\right\}$$

- **Non-obstruction constraint :**

$$r_2 = h_{a2} \Big/ sin\left\{\frac{U_{a2}}{2} + \frac{arctan\left[(CLEAR1 - h_{b1} + h_{a2}) / (-d_1 - z_{a2} + z_{b1})\right]}{2}\right\}$$

G3: Image side group



Second: We choose the adequate WDI **and** d_5 **due to design requirements and incidence angles constraints**

G3: Image side group

r_5 : radius of M5

r_6 : radius of M6

The mirror radius can be calculated with the defined parameters and the constraint:

- **Non-obstruction constraint:**

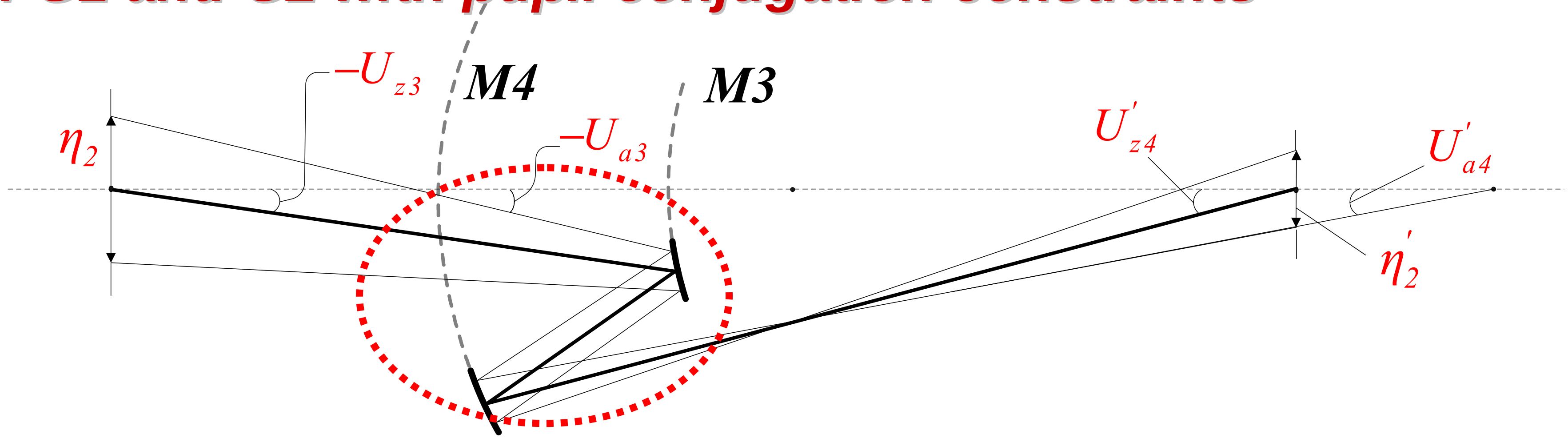
$$r_5 = h_{a5} \Big/ \sin\left\{\frac{U_{a5}}{2} + \frac{\arctan\left[(CLEAR6 + h_{a5} + h_{b6})/(-d_5 + z_{b6} - z_{a5})\right]}{2}\right\}$$

- **Non-obstruction constraint:**

$$r_6 = h_{a6} \Big/ \sin\left\{\frac{U_{a6}}{2} - \frac{\arctan\left[(CLEAR5 - h_{bD1} + h_{a6})/(-d_5 + z_{a6} - z_{bD1})\right]}{2}\right\}$$

G2: Middle group

The middle group should connect the light path and pupils of G1 and G2 with pupil conjugation constraints



Parameters given in G1 and G3:

η_2 **The diameter of G2's entrance pupil (the diameter of G1's exit pupil)**

η'_2 **The Diameter of G2's exit pupil (the diameter of G3's entrance pupil)**

G2: Middle group

$-U_{z3}$ Chief ray angle of incidence in middle group

U'_{z4} Chief ray angle of exitance in middle group

$-U_{a3}$ Upper ray angle of incidence in middle group

U'_{a4} Upper ray angle of exitance in middle group

Configuration parameters:

To be calculated next.

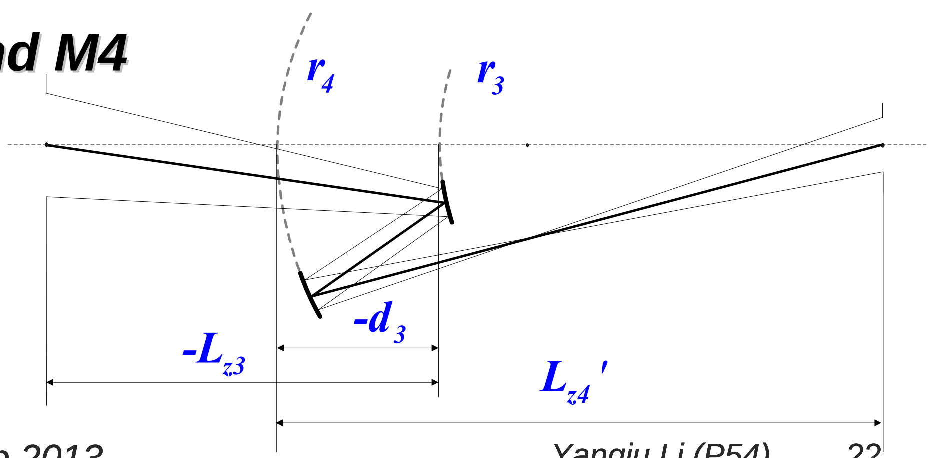
L_{z3} Distance between entrance pupil and M3

L_{z4}' Distance between exit pupil and M4

d_3 Distance between M3 and M4

r_3 Radius of M3

r_4 Radius of M4



G2: Middle group

Real ray trace equations under Conjugation conditions:

$$\sin I_{z3} = \frac{L_{z3} - r_3}{r_3} \times \sin U_{z3}$$

$$U_{z3}' = U_{z3} + 2I_{z3}$$

$$L_{z3}' = r_3 \times \left(1 - \frac{\sin I_{z3}}{\sin U_{z3}'}\right)$$

$$L_{z4} = L_{z3}' - d_3$$

$$\sin I_{z4} = \frac{L_{z4} - r_4}{r_4} \times \sin U_{z3}'$$

$$U_{z4}' = U_{z3}' + 2I_{z4}$$

$$L_{z4}' = r_4 \times \left(1 - \frac{\sin I_{z4}}{\sin U_{z4}'}\right)$$

$$L_{a3} = L_{z3} + \frac{\eta_2}{2 \times \tan U_{z3}}$$

$$\sin I_{a3} = \frac{L_{a3} - r_3}{r_3} \times \sin U_{a3}$$

$$U_{a3}' = U_{a3} + 2I_{a3}$$

$$L_{a3}' = r_3 \times \left(1 - \frac{\sin I_{a3}}{\sin U_{a3}'}\right)$$

$$L_{a4} = L_{a3}' - d_3$$

$$\sin I_{a4} = \frac{L_{a4} - r_4}{r_4} \times \sin U_{a3}'$$

$$U_{a4}' = U_{a3}' + 2I_{a4}$$

$$L_{a4}' = r_4 \times \left(1 - \frac{\sin I_{a4}}{\sin U_{a4}'}\right)$$

$$L_{a4}' = L_{z4}' - \frac{\eta_2'}{2 \times \tan U_{a4}'}$$

$$\frac{1}{r_3} - \frac{1}{r_4} = \left(-\frac{1}{r_1} + \frac{1}{r_2}\right) + \left(-\frac{1}{r_5} + \frac{1}{r_6}\right)$$

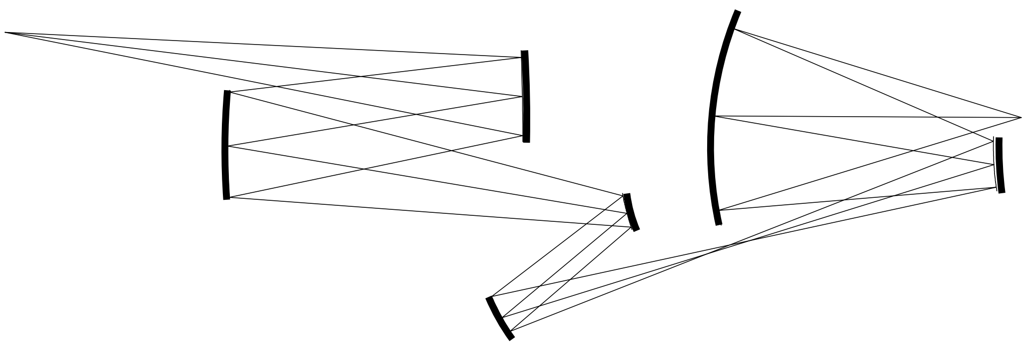
Then, we can get parameters of r3, r4, d3, Lz3 and Lz4'

Connection of G1, G2 and G3

There are 17 equations and 17 variables including 5 parameters of middle group.

(the other 12 variations are defined in appendix).

The configuration of G2 with lower incidence angles on mirrors will be chosen to connect the G1 and G3.

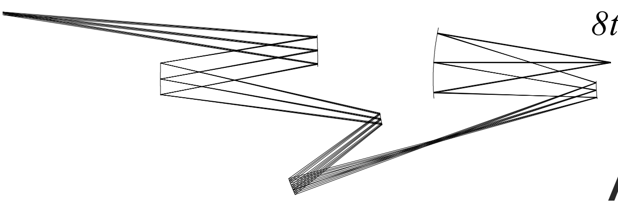


With this method, an initial spherical objective with low incidence angles is obtained.

Gradual Optimization

Then, aspheric coefficients are added gradually , and the system is optimized gradually too. Finally a high quality *EUVL* ***objective design is completed.***

Variable setting : 4th order coeffcient
6th order coeffcient
8th order coeffcient

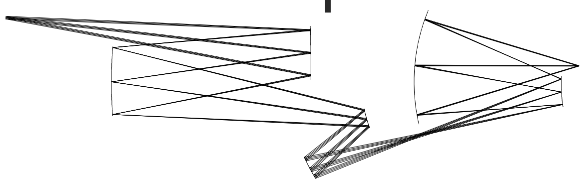


Asp. 8th

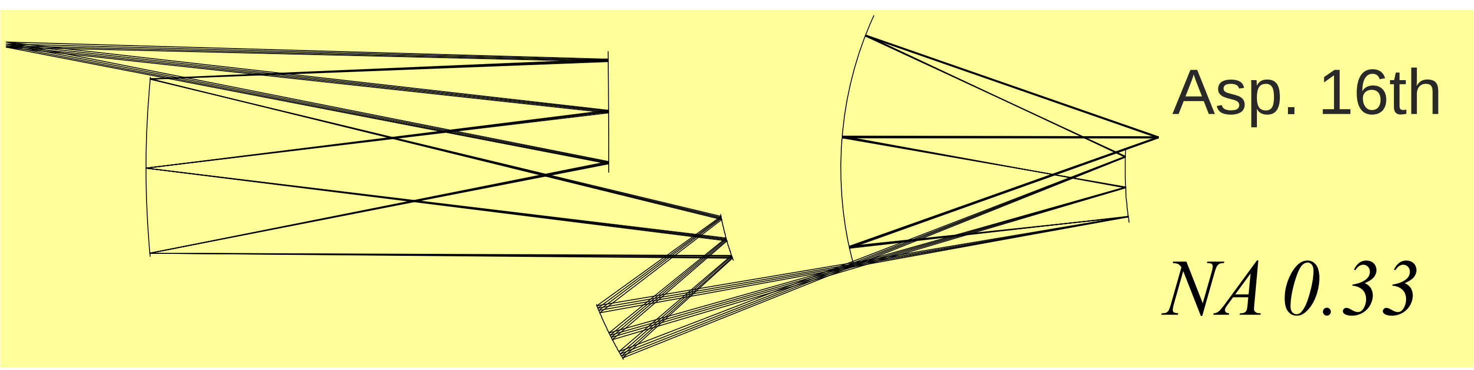
NA 0.15

Asp. 12th

Variable setting : 4th order coeffcient
6th order coeffcient
8th order coeffcient
10th order coeffcient
12th order coeffcient
all the radius
all the thicknesses

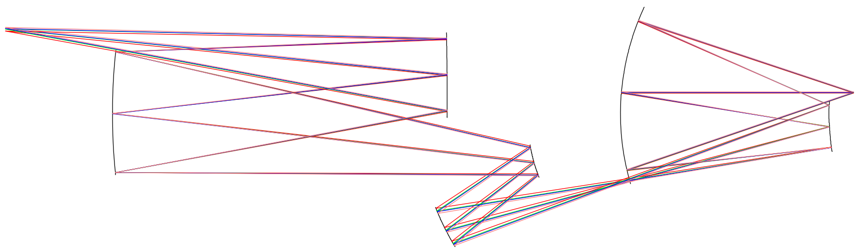


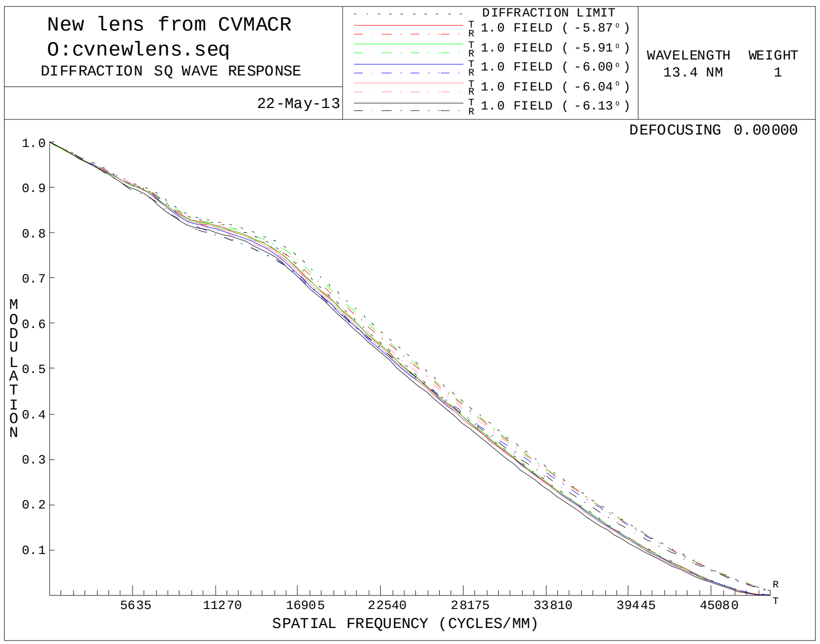
NA 0.3



Variable setting : 4th order coeffcient
6th order coeffcient
8th order coeffcient
10th order coeffcient
12th order coeffcient
14th order coeffcient
16th order coeffcient
all the radius
all the thicknesses

Performance of the Objective



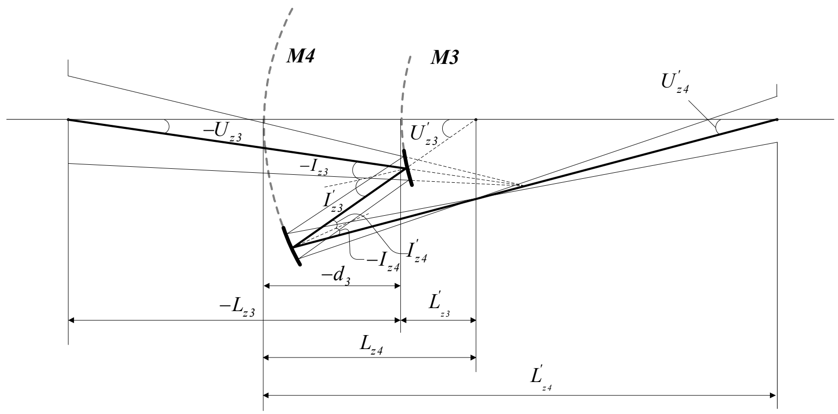


Wavelength	13.5nm
Numerical aperture	0.33
A field of view	26mm×1.5mm
Reduction radio	4
Total track	1373mm
working distance	40mm
Chief ray angle on mask	<6.0°
Chief ray angle	<22.4°
Wave front error (RMS)	0.02128 λ
Distortion (σ =0.5~0.8)	2.2nm
CD error (σ =0.5~0.8)	1.2%
Aspherical departure	< 40um

Conclusions

- ***A grouping design method using off axis real ray calculation is proposed.***
- ***The method is effective for reducing design variables and controlling incidence angles on reflective mirrors.***
- ***With this method, the initial configurations of objective is suitable for further optimization to meet the requirements***

Appendix



Parameters of chief ray:

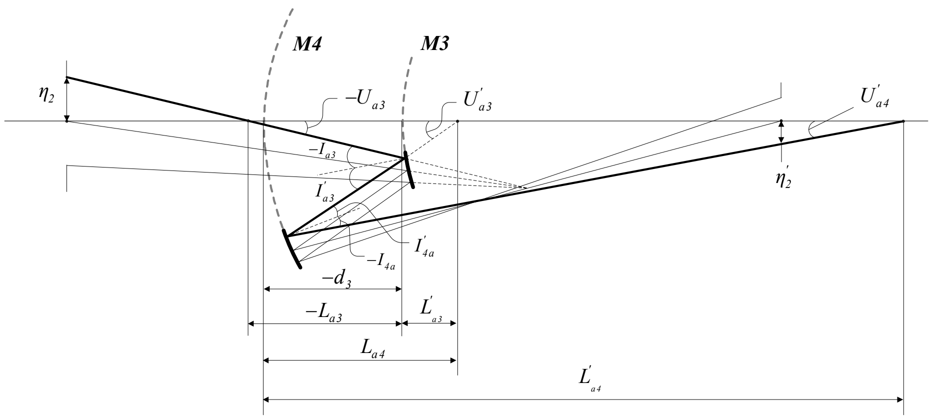
I_{z3} Incidence angle of M3

I_{z4} Incidence angle of M4

U'_{z3} Image-side aperture angle of M3

L'_{z3} Image-side intercept of M3

L_{z4} Object-side intercept of M4



Parameters of upper ray:

I_{a3} Incidence angle of M3

I_{4a} Incidence angle of M4

L_{a3} Object-side intercept of M3

L'_{a3} Image-side intercept of M3

L_{a4} Object-side intercept of M4

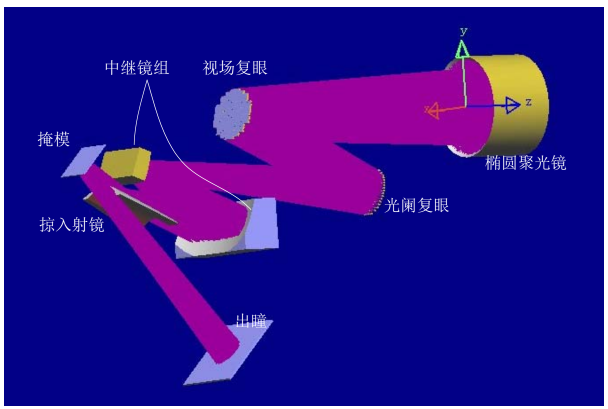
L'_{a4} Image-side intercept of M4

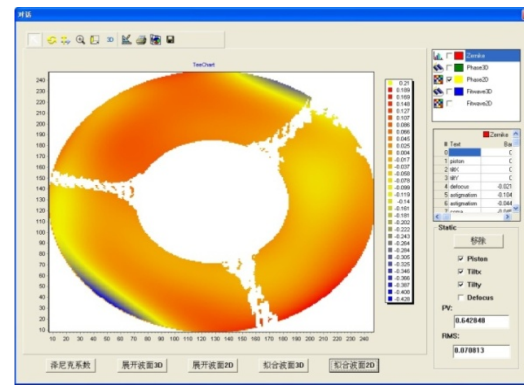
U'_{a3} Image-side aperture angle of M3

Acknowledgment

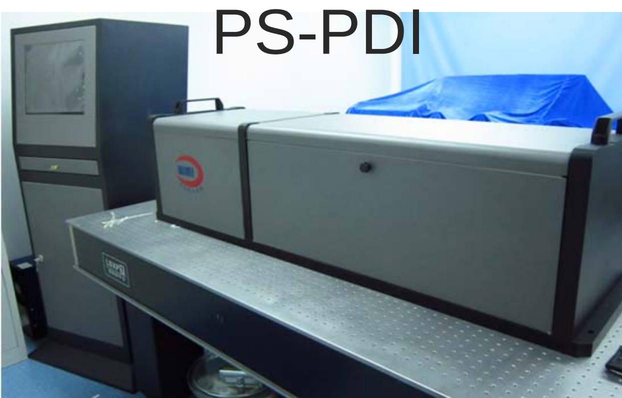
This work is supported by

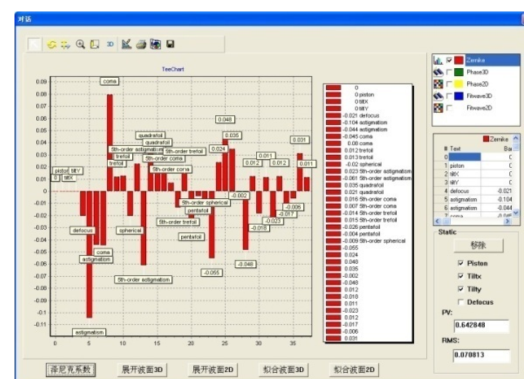
National Science and Technology Major Project.





PS-PDI





Thanks for your attention!